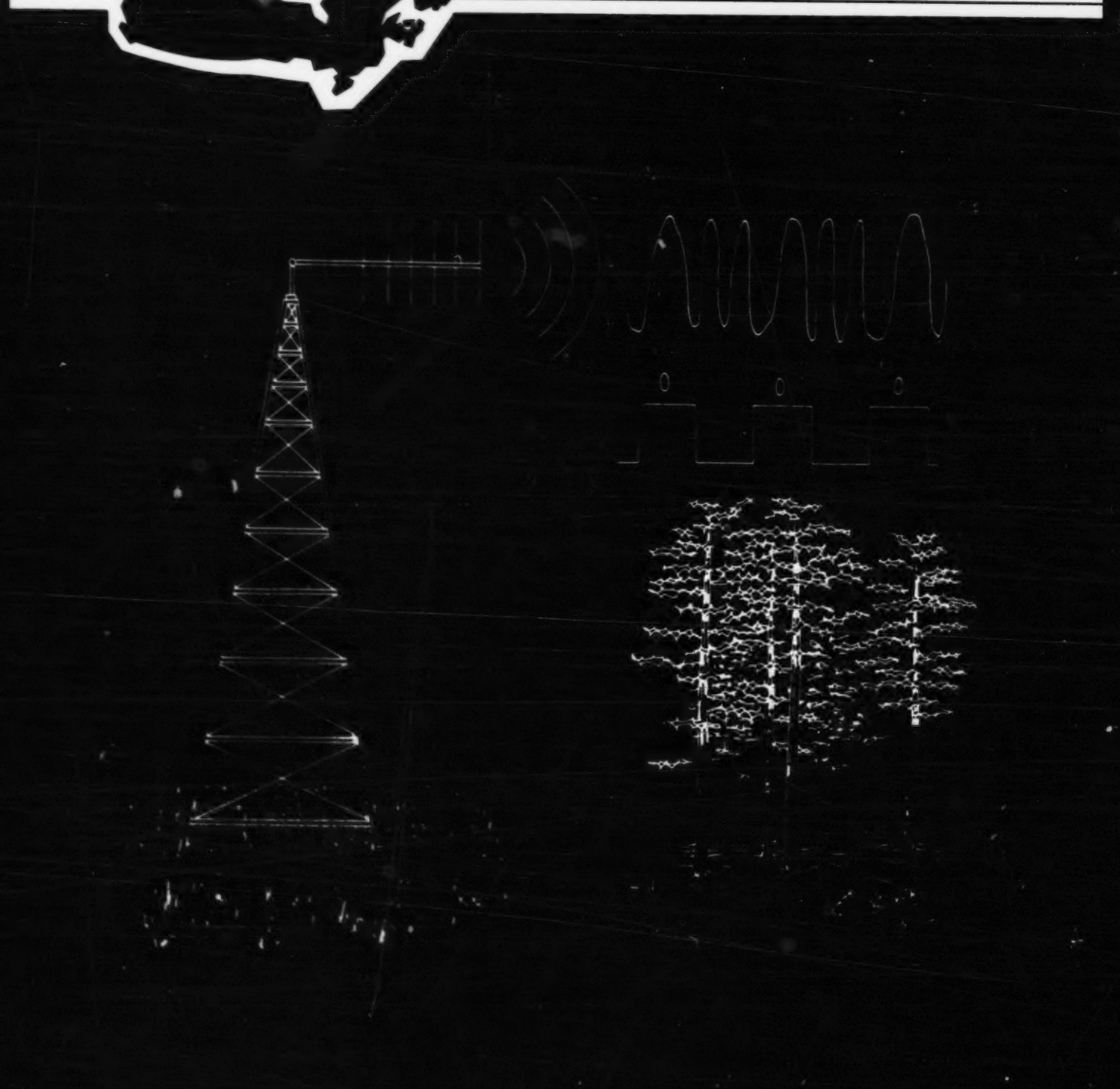
Government of Canada | Gouvernement du Canada
Canadian Forestry Service | Service canadien des forêts

UHF Radio Transmission of Forestry Data

B.E. Mroske and P.H. Kourtz

Information Report PI-X-63
Petawawa National Forestry Institute



86-04713/

PETAWAWA NATIONAL FORESTRY INSTITUTE

In common with the rest of the Canadian Forestry Service, the Petawawa National Forestry Institute has as its objective the promotion of better management and wiser use of Canada's forest resource to the economic and social benefit of all Canadians. Objectives of program activities carried out at the Institute support this goal through discovery, development, demonstration, implementation, and transfer of innovations. Because it is a national institute, particular emphasis is placed on problems that transcend regional boundaries or that require special expertise and equipment that cannot be duplicated in CFS regional establishments. Such research is often performed in close cooperation with staff of the regional centres or provincial forest services.

Research initiatives and technical services at the Institute encompass six major activities:

FOREST GENETICS AND BIOTECHNOLOGY — Integrates projects in tree genetics, soil microbiology, micropropagation, molecular genetics, and seed research. It also includes the client services and seed bank operations of the National Tree Seed Centre, a long-standing program with extensive international affiliations.

FOREST MANAGEMENT SYSTEMS — This program integrates projects in fire, remote sensing, meteorology, modelling, growth and yield, and FIDS to provide research and development for the formulation and demonstration of forest management systems.

NATIONAL FOREST RESOURCE STATISTICS — Widely known as FORSTATS, this program coordinates the acquisition, standardization, and publication of national statistics on the forests of Canada, and responds to client requests.

FOREST DATA SYSTEMS — Provides the expertise and computer-based systems necessary to manage data acquired through FORSTATS and the research projects at PNFI. Additionally, the program provides informatics advice and service at the CFS corporate level.

COMMUNICATIONS — Integrates activities of the library, public awareness, information, and editing and publications projects. The Institute is visited by more than 20 000 people every year. There is a Visitor Centre for the public, self-guided tours, and an extensive education project. The national repository of all scientific and technical publications of the CFS is at PNFI.

THE RESEARCH FOREST — Besides natural stands manipulated in a variety of ways for silvicultural research, the 98 km^2 Petawawa Forest contains extensive areas of plantations dating back six decades. Research plantations are a source of growth and yield data derived from cultural experiments, and they are becoming valuable for pedigreed genetic materials for micropropagation and molecular genetics studies. The forest also offers opportunities for short- and long-term testing of forest management strategies.

UHF RADIO TRANSMISSION OF FORESTRY DATA

Information Report PI-X-63

B.E. Mroske and P.H. Kourtz

Petawawa National Forestry Institute
Canadian Forestry Service
Chalk River, Ontario

1986

©Minister of Supply and Services Canada 1986
Catalogue No. Fo46-11/63-1986E
ISSN 0706-1854
ISBN 0-662-14737-5

Additional copies of this publication can be obtained from

Technical Information and Distribution Centre
Petawawa National Forestry Institute
Chalk River, Ont.
K0J 1J0

Telephone: 613-589-2880

Cette publication est aussi disponible en français sous le titre **Transmission de données forestières par radio à ultra-haute fréquence.**

Contents

v	Abstract/Résumé
1	Introduction
3	Forest fire management data communication problems
4	Objectives
4	System design
7	Licence requirements
9	Installation of the trial telemetry system
15	Results
16	Discussion
19	Acknowledgments
19	References
20	Appendix I
21	Appendix II

ABSTRACT

Canadian forest fire management agencies use automated data collection systems that collect and transmit data from remote locations to central sites on a continuous or near-continuous basis. These systems require dedicated data communication services. The absence of data communication services for preferred data collection sites can severely limit the usefulness of these systems.

A study was conducted to determine the feasibility of using UHF radio for continuous medium and long distance data transmission from remote areas. A UHF radio data link was configured and implemented. The system was designed to transmit lightning information continuously over a distance of 90 kilometers. The performance of the radio link was monitored and compared to a parallel land line.

Initial results indicate that, for a limited time period, data can be economically and reliably transmitted on a continuous basis by the UHF radio link described in this paper. If the system exhibits long term reliability it will be a feasible data communication alternative. The economics of particular applications, support capability, and radio frequency availability are the major factors that will determine the feasibility of transmitting data by radio.

RÉSUMÉ

Les organismes canadiens qui s'occupent de la gestion des incendies de forêt emploient des systèmes automatisés de collecte qui recueillent des données dans les endroits éloignés et les transmettent à des centres de façon continue ou quasi-continue. Ces systèmes exigent des services spécialisés de communication des données, et leur utilité peut être considérablement réduite s'il n'existe pas de services pour les stations de collecte prioritaires.

Une étude a été effectuée dans le but de savoir s'il était possible de transmettre continuellement par radio UHF, à longue et à moyenne distances, des données recueillies dans les régions éloignées. Un système de communication des données par radio UHF a été mis au point et à l'essai. Le but visé consistait à transmettre continuellement, sur une distance de 90 kilomètres, des données sur la foudre. Le rendement du système a été contrôlé et comparé à celui d'un système parallèle de communications par voie terrestre.

Les premiers résultats indiquent que, pour une période de temps limitée, les données peuvent être transmises continuellement de façon économique et fiable, grâce au système de communication par radio UHF décrit. Si le système s'avère fiable à long terme, il sera possible de l'utiliser pour la communication des données, compte tenu des principaux facteurs suivants: la rentabilité des applications spéciales, la capacité de soutien et la disponibilité de radio-fréquences.

INTRODUCTION

Canadian forest fire management agencies have implemented and are continuing to implement automated data acquisition systems. These systems and associated concepts such as centralized information processing are incorporated at various levels within a fire protection organization and often require sophisticated data communication support. In certain situations the inflexibility, cost, complexity, or absence of data communication services severely limits the use of remote data collection systems.

The above data communication problems are usually most critical where applications require movement of data to and/or from sparsely settled areas. As forest fire agencies are responsible for protecting vast and remote areas of Canada's north, it is a frequent requirement to obtain data from remote locations. Data, such as cloud to ground lightning location, is obtained at a remote site and transmitted to some central planning and decision making centre. Data transmission may be nearly continuous during severe thunderstorms. For this type of application, data communication alternatives are limited or, in some instances, nonexistent.

Dedicated long distance telephone lines are normally used to provide data transmission. However, agencies may experience difficulty in obtaining a single pair of wires to transmit data from a remote collection point to some central point. If available, the telephone lines may be very expensive to lease, and unreliable because of line noise. Satellite and ionized meteor trail systems (Meteor Communications Consultants 1981) may be used to achieve long distance data transmission from remote locations. These systems use the radio frequency (RF) spectrum (Fig. 1) as the data transmission medium. The satellite and meteor trail function as radio repeaters. Dedicated satellite facilities have been prohibitively expensive and meteor burst technology is limited by the duration of meteor trails. For forest protection purposes, these systems have been feasible data transmission alternatives when applications involve limited amounts of data, such as data transmission from remote weather stations.

There has been a recent increase in the use of RF media for data transmission. In addition to satellite and meteor burst systems, major advances have been achieved in the use of RF wavelengths for land-based, short distance data transmission. These local area networks offer capabilities similar to some advanced cable systems. Concepts such as frequency sharing (multiplexing) and the interrogation of remote stations (polling) are utilized. In addition, the networks can operate as a mobile service. A radio frequency rather than cable is used as the transmission medium. Electronic circuits are used to embed data in the radio frequency. These circuits systematically alter some characteristic of the radio frequency waveform such as amplitude, frequency, or phase in a manner that can represent digital data. The frequencies most often used are in the very high frequency (VHF) and ultra high frequency (UHF) range (Table 1).

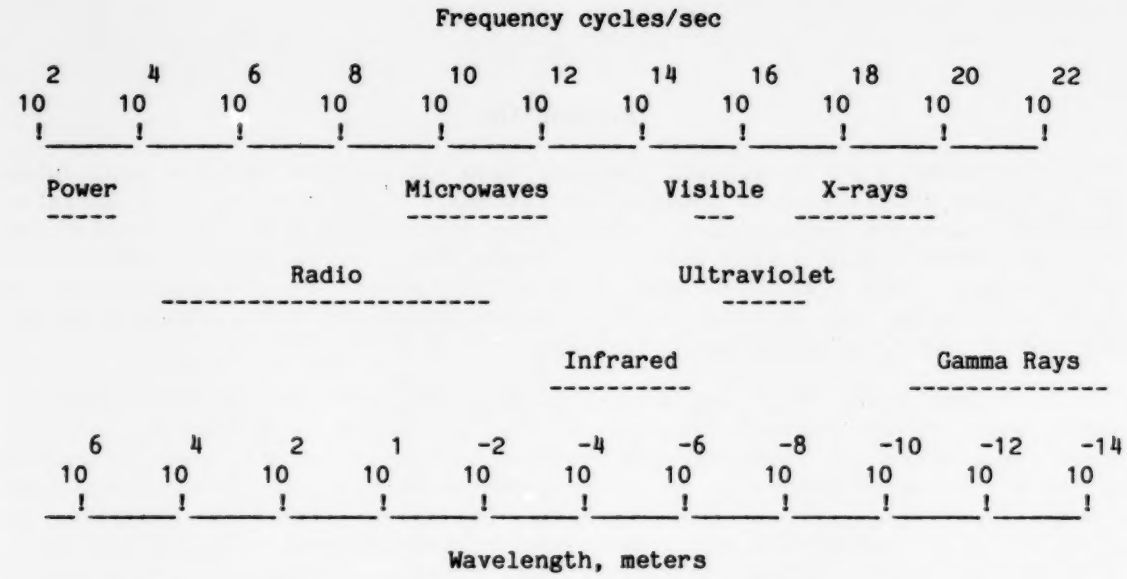

Frequency cycles/sec
2 4 6 8 10 12 14 16 18 20 22
10 10 10 10 10 10 10 10 10 10 10
Power
Microwaves
Visible
X-rays
Radio
Ultraviolet
Infrared
Gamma Rays
6 4 2 1 -2 -4 -6 -8 -10 -12 -14
10 10 10 10 10 10 10 10 10 10 10
Wavelength, meters

Figure 1. The Electromagnetic Spectrum. Overlap indicates that certain wavelengths may be produced by different techniques.

Table 1. Radio-frequency spectrum

Frequency	Wavelength	Classification
Less than 30 kc/sec	Above 10,000 m	Very Low Frequency VLF
30-300 kc/s	10,000-1000 m	Low Frequency LF
300 kc/s-3 Mc/s	1000-100 m	Medium Frequency MF
3-30 Mc/s	100-10 m	High Frequency HF
30-300 Mc/s	10-1.0 m	Very High Frequency VHF
300-3000 Mc/s	1.0-.1 m	Ultra High Frequency UHF
3-30 Gc/s	0.1-0.01 m	Super High Frequency
30-300 Gc/s	0.01-0.001 m	Extra High Frequency

Land-based data transmission by VHF/UHF radio may be a feasible solution to some forest fire protection data communication problems. The radio spectrum is usually less crowded in isolated areas; this would facilitate the approval of requests for the use of radio frequencies. Therefore, the availability of the VHF and UHF radio frequencies increases with the remoteness of an application. Also, fire management organizations usually operate large and sophisticated voice radio networks. Resources and facilities associated with voice radio systems such as frequencies, radios, radio expertise, repeater configuration, test equipment, and signal path analysis can also apply to data transmission radio systems. In addition, radios are portable and can be used for mobile data communication.

The Petawawa National Forestry Institute (PNFI), in cooperation with the Société de Conservation de l'Outaouais (SCO), Maniwaki, Quebec, initiated a study to help determine the role of radio in medium and long distance data transmission from remote areas. A UHF telemetry system to transmit data by radio was configured and implemented. This paper provides a background on specific data communication problems, outlines study objectives, describes the design and implementation of the telemetry system, and presents and discusses study results.

FOREST FIRE MANAGEMENT DATA COMMUNICATION PROBLEMS

A variety of data communication needs are associated with forest fire management activities. The following description of specific applications provides an insight to the problems.

Microprocessor-based lightning sensors are located throughout Canada to provide real time information on the characteristics and location of cloud to ground lightning flashes. The information is a vital input to daily planning and decision making processes. The sensors are strategically placed throughout forested areas in a manner which will maximize coverage and accuracy. The remote microprocessors (direction finders) are linked to a central microprocessor (position analyzer) which calculates flash locations if timing criteria are met. Data is usually transmitted by land line in either point to point or polled configuration. Required transmission speeds range from 300 baud to 2400 baud (30 to 240 characters/sec). The absence of data communication facilities for preferred sensor sites results in less efficient lightning networks or, in certain instances, a complete lack of lightning system coverage. Radio communications could, in many instances, improve lightning system coverage.

A low cost digital weather radar has been developed by McGill University for the Canadian Forestry Service. The radar design incorporates features which allow for remote installation. A microprocessor at the radar site transmits digital rainfall rates every 2½ minutes for approximately 8000 sample elements. A microcomputer at some central site receives the data and controls the radar operation. A 1200 baud data transmission link is required between the two microcomputers. Ideally, effective range, required coverage, and terrain effect should dictate radar site selection. However, as with lightning, the absence of data transmission facilities may confine the radar to undesirable sites. Radio communications would permit more flexibility.

Advances are continually being made in the development of computer-based decision support systems for forest fire management. Computer terminals, microcomputers, and minicomputers at coordination or command centres are becoming common. A variety of software and hardware is available to assist decision makers. Continued advancement, in conjunction with improved database information, will result in a requirement for on-line computer support at forest fire sites. Applications would include modelling fire behaviour and determining the effects of proposed suppression tactics. These applications will require mobile data communications. At present, data communication by radio is the only feasible alternative.

OBJECTIVES

The above applications require differing levels of sophistication in data transmission systems. Under stormy conditions, for example, a point to point lightning system will transmit almost continuously in a simplex mode. (Simplex mode is the transmission of data in one direction only and duplex mode is the transmission of data in both directions.) The radar application will require a continuous and duplex data link. Polled lightning systems require full duplex (simultaneous two way data transmission) support. Terminals at fire sites will require mobile and duplex data communication capability. The telemetry system described in this paper is a simplex system designed to capture lightning data by UHF radio. Of major concern is the feasibility of establishing a medium distance radio link that will transmit data reliably on a continuous or near-continuous basis. If desired, more advanced features such as polling and duplexing could be incorporated to the system.

The study had four main objectives. The first objective was to design a theoretical system that could be presented as an engineering brief to the federal Department of Communications (DOC). The second goal was to obtain system approval by DOC, and licensing. Thirdly was the implementation of infrastructure and installation of hardware. The final goal was to evaluate system performance and assess the potential for operational use.

SYSTEM DESIGN

Of the various systems examined, the one designed and used by the Department of Energy, Mines, and Resources (Meldrum 1980) appeared the most appropriate to forest fire needs. The system used UHF radio to capture seismology data from remote locations. Desirable system features included low cost, low power use, an operating speed of up to 4800 baud (500 characters/sec), simplicity of repeater configuration, a suitable operating frequency and a digital mode of operation. A brief explanation of digital radio and modulation concepts is presented in Appendix I.

The EMR system is a modified Repco[1] radio, which is the type approved as EMR-100 for the 450-470 MHz band. The voice processing circuits of the radio are replaced by EMR-designed FSK modulator and demodulator circuits. The first few bits of information in a message are used by the

[1]Repco Incorporated, Orlando, Florida.

demodulator to determine whether the operating frequency has drifted. The signal processing is adjusted accordingly. This procedure can be viewed as the continuous automatic tuning of a radio station dial to achieve best reception. The monitoring of the initial bits of information results in the loss of several leading characters each time a message is initiated. The problem could be avoided by adding a data preamble to a message; however, due to the nature and variety of forestry applications the problem was resolved by redesigning the demodulator circuit.

The audio amplifier module of the radio transmitter is replaced by a digital interface module. This module generates the mark and space voltage levels. The voltage level generated is input to the transmitter FM modulator/oscillator module so that the radio will generate the proper FM signal. There are no modifications to existing receiver circuitry. The demodulator is simply added to the receiver unit. The circuit is capable of outputting data in the RS232 standard. The modified receiver and transmitter were submitted for type approval for the 406-420 MHz band. The equipment is shown in Figures 2 and 3.

The following paragraph discusses the radio transmission aspects of the telemetry system. Appendix II provides a brief description of some radio transmission concepts.

The Repco 819 transmitter series ranges from 0.2 to 4 watts of power output. The radios can operate continuously at half the maximum power rating. Transmitters with a 1 to 2 watt rating were used to achieve continuous transmission duty at 1 watt output or 0 dBW gain. The radio draws approximately 300 mA when transmitting at 1 watt. An SRL-307[1] seven element yagi antenna rated at a 10.0 dB gain was the proposed radiator. In some cases 2 antennae were stacked to achieve a 12 dB gain. Effective radiation for the various transmitting sites ranged from 8 to 10 dBW. The receiver was also coupled to an SRL-307 antenna which provides an additional 10 dB gain. The receiver had a required minimum signal level of -137 dBW. Minimum signal was the level at which the radio cannot differentiate between the signal and internally generated receiver noise. This configuration has a total allowable signal loss of approximately 150 dB (receiver sensitivity plus the gain of two antennae minus cabling losses). In theory, at 410 MHz and a required fade margin of 25 dB at the receiver, the system could provide land hops of up to 160 kilometers if free space (signal loss due to distance between antennae with no obstructions by earth or atmosphere) were the only path attenuation. However, the achievable distance is usually considerably less than 160 kilometers because of earth curvature, terrain, and atmospheric effects.

It was proposed to establish three radio links in the southwestern region of Quebec. Two links would be of simplex mode dedicated to the capture of real time lightning data. Transmission would be from Ft. Coulonge to Maniwaki and from Le Domaine to Maniwaki. Each link is a straight-line distance of approximately 100 kilometers. The third proposed path was a full duplex link between Petawawa, Ontario, and Maniwaki, Quebec, a distance of 160 air kilometers. This link was to support interactive computing and data exchange between PDP11 minicomputers at Petawawa and Maniwaki. The Le Domaine-Maniwaki link was implemented and is discussed in detail. The

---

[1]Sinclair Radio Laboratories Inc., Montreal, Quebec.

Figure 2. Radio Transmitter

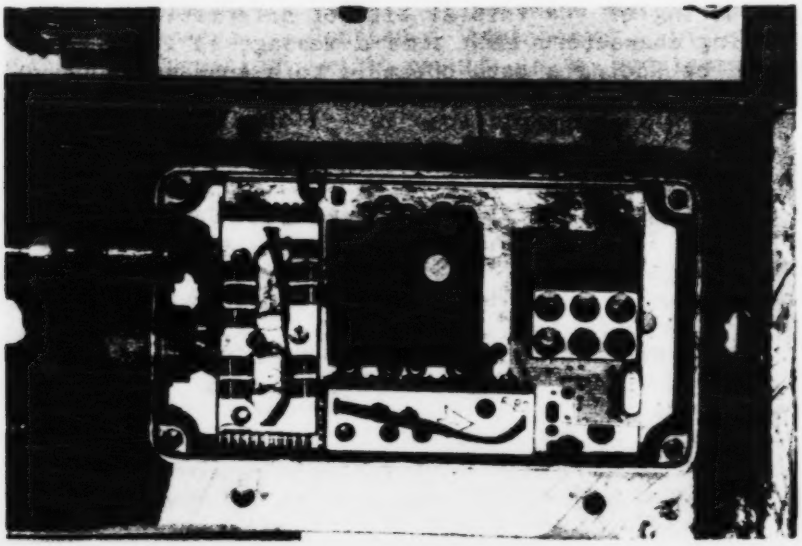
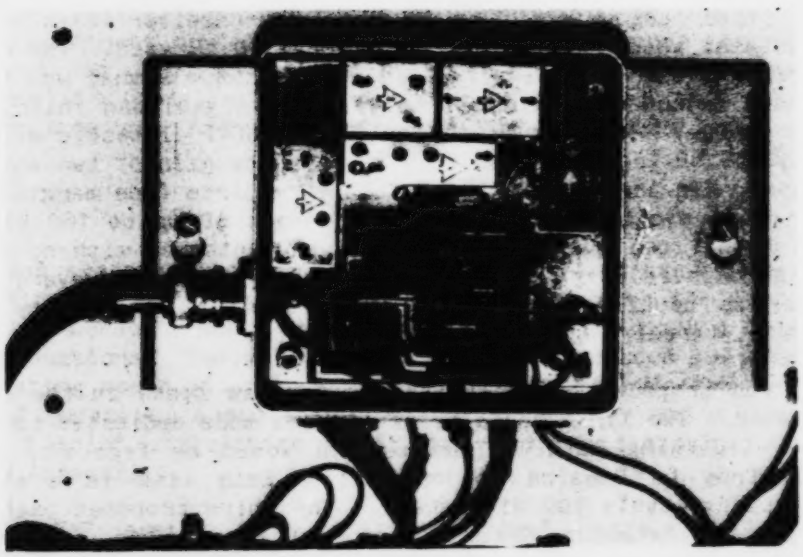


Figure 3. Radio Receiver



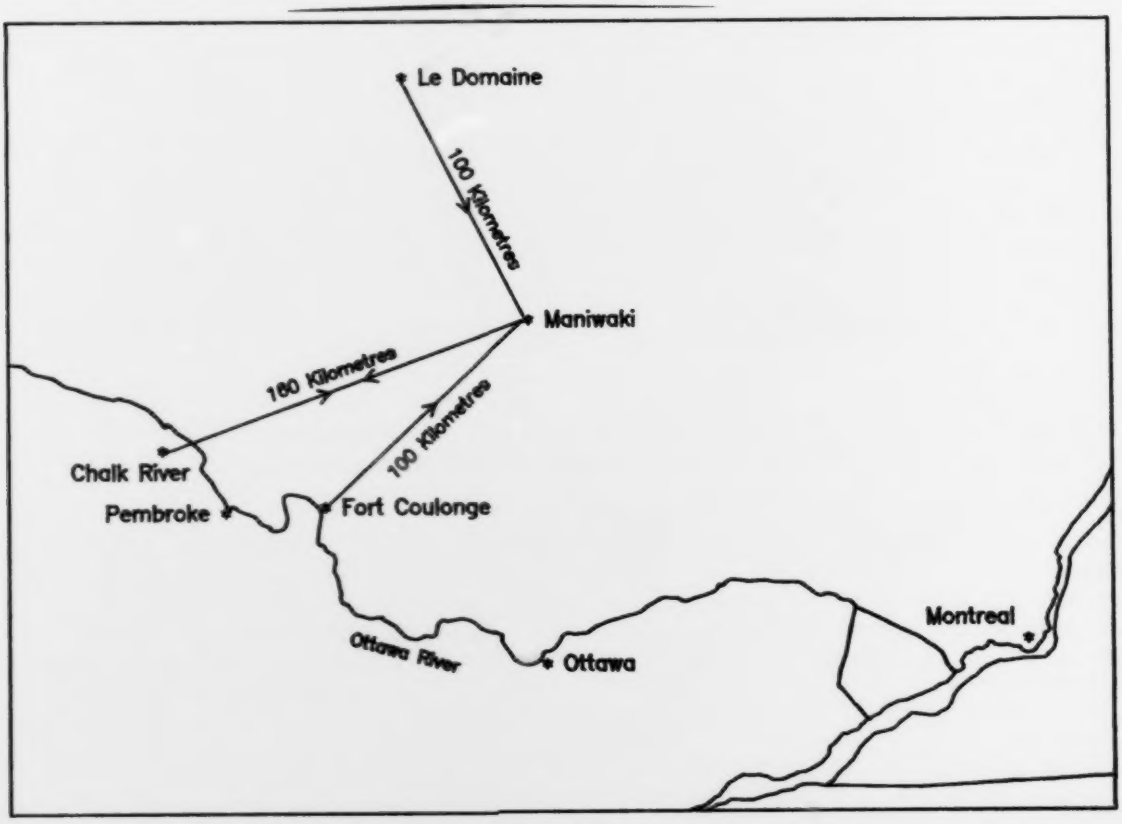
remaining links were not implemented but were part of the UHF telemetry proposal submitted to the federal Department of Communications (DOC) (see Figure 4.)

The topography of the region posed severe problems to UHF communications. The area is characterized by an undulating terrain with many peaks and ridges. It was difficult to obtain signal paths of more than 50 kilometers without severe attenuation problems. In addition, the receiving site was situated in a valley. Path calculations indicated that two repeater sites were required for the Ft. Coulonge to Maniwaki lightning link and three repeater sites for the remaining two links. An application and region more conducive to UHF transmission would simplify the configuration, but terrain and receiving site problems as described above are common throughout Canada's forested area. Thus, the proposed design was realistic.

LICENSING REQUIREMENTS

The federal Department of Communications allocates frequencies, authorizes implementation of radio systems, and monitors radio transmissions. For this study, two major briefs were submitted to the department to obtain permission to install and operate the telemetry system.

Figure 4. Proposed radio links



The first submission was an engineering report (Chinnick 1982) in support of a request for radio certification. Certification of radio equipment means that the equipment complies with technical specifications, standards, or requirements established by the DOC. Because no similar equipment had been certified for direct frequency shift keying in the 406 to 420 MHz band it was necessary to show that the modified radios met DOC standards. The report describes the results of a series of tests. The tests were conducted in accordance with Radio Standards Procedure Number 100 and Radio Standards Specifications Number 120 as a guide. The tests were carried out and certified by Foundation Electronic Instruments Inc., Ottawa, Ont. The transmitter tests include unmodulated RF carrier output, spurious radiation characteristics, and carrier frequency stability. The receiver was tested for spurious outputs. The modified radios were certified as DOE-406.

The second submission was an engineering brief (Mroske and Bussierre 1983) describing the proposed telemetry system. The brief consisted of system justification, request for frequencies, system layout, equipment specifications, site details, and application for a license to operate the telemetry system. Conversations with DOC personnel prior to formal application indicated that there was little chance of obtaining the use of VHF frequencies for the area of interest and that UHF frequencies would probably be available in the 406 to 420 band. Thus the DOC informal recommendation, in conjunction with the relative noise immunity of UHF to stormy weather, dictated the operating frequency range. A request was made for use of 10 pairs of frequencies in the 406 to 420 band and permission to use 6 pairs was granted.

The proposed links are serviced at present with telephone lines. The justification was one of economics and reliability. It was proposed that the cost of renting one telephone line and associated modems for a fire season is equivalent to the cost of installing a radio link with one repeater. At present, the land line lightning links, including modems, are leased for approximately 1000 dollars per month.

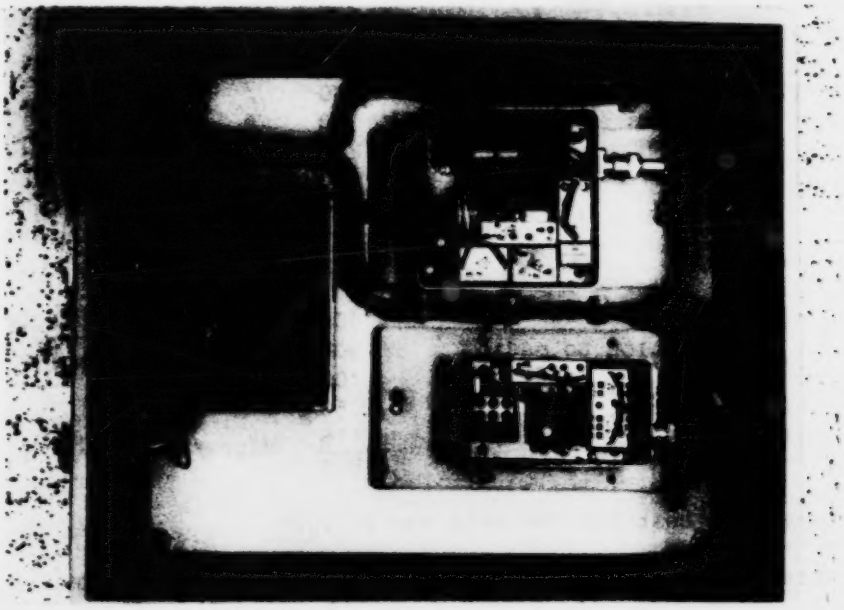
Lightning detection and weather radar equipment provide stormy and wet weather information. Unfortunately, these weather conditions are a major source of data communication problems when using land lines. The most common problem is one of line noise. A less common but severe problem is that of damage to equipment resulting from lightning induced power surges on communication lines. Thus, the most valuable information is being collected when data transmission conditions are least reliable. It was proposed that the telemetry system would be more reliable than telephone lines. For areas without any data communication services, justification would simply be the lack of communication alternatives.

A set policy for use of radio for data transmission was not encountered. Department of Communications personnel stated that requests for permission to install similar systems would be judged on the individual merits of proposals. Permission was received to implement the telemetry system. The preparation of reports and the subsequent approval process took approximately six months.

INSTALLATION OF THE TRIAL TELEMETRY SYSTEM

Foundation Electronic Instruments Inc. was contracted to redesign the demodulator board. The company also configured one transmitter, one receiver, and a repeater unit consisting of a back to back receiver and transmitter. The transmitter and receiver were located at sites where AC power was available. A solar panel system was used as the power supply for repeater sites. Two 70 amp-hour wet cell batteries provided a 10 day reserve, and were charged by a 55 watt solar panel. The radios and associated power supply units were installed in compact and weatherproof housing. Foundation Instruments provided a supply of spare parts and informal documentation on the modified demodulator. A second repeater was built by the SCO radio/electronics technician (see Figure 5.)

Figure 5. Radio Repeater



The cost of equipment is outlined below.

Transmitting Unit at Le Domaine

radio transmitter	$ 600
commercial modification to radio (includes packaging, power supply, and digital circuit)	900
two antennae	230
cabling and connectors	50
tower	200
Total	$1980

Repeater at Perdrix Blanche

radio transmitter	$ 600
radio receiver	800
commercial modification to radio	900
2 antennae	230
cabling and connectors	50
solar panel	800
batteries	200
solar panel mounting kit	200
Total	$3780

Repeater at Lac Blue Sea

radio transmitter	$ 600
radio receiver	800
in-house modification to radio	200
2 antennae	250
solar panel	800
batteries	200
solar panel mounting kit	200
protective enclosure	300
tower	200
cabling and connectors	100
Total	$3300

Receiver at Maniwaki

radio receiver	$ 800
commercial modification to radio	900
tower	100
cabling and connectors	50
one antenna	115
Total	$1965

The total equipment cost for the path was $11,025.

Because of the availability of an old fire lookout tower which could serve as a repeater site, the link between the direction finder at Le Domaine and the position analyzer at Maniwaki was chosen as the first link to implement. The link involved three hops. The resulting signal paths are outlined in Tables 2, 3, and 4. Prior to installation, signal path performance was checked by attempting UHF voice communication by handheld portables which approximated the radio link power and sensitivity specifications. Miniature speakers were added to the receiver units to provide a quick check of performance of individual repeater hops. When the speakers are manually activated data transmission can be monitored as a series of audible tones. The speakers are most valuable at remote repeater sites not serviced by AC power and where the use of elaborate test equipment is cumbersome. In addition, an estimate of available fade margin can be achieved by adding predetermined attenuation to the signal path and monitoring the degradation of tone response.

Table 2. Transmission calculation

PATH: Le Domaine to Perdrix Blanche

Effective height station 1	13 m	
Effective height station 2	160 m	
Distance in kilometers	50 km	
Transmitter power 1 watt		0 dBW
Cable and connector loss		-1.5 dB
Antenna gain		12.0 dB
Effective radiated power		10.5 dBW
Free space loss	dB	
Plane earth loss	-117.2 dB	
Obstruction loss	-9.5 dB	
Total propagation loss		-126.7 dBw
Received signal strength		-116.2 dBW
Antenna gain		10.0 dB
Cable and connector loss		-0.7 dB
Receiver input signal		-106.9 dBw
Minimum required signal		-137.0 dBw
Fade margin		30.1 dB

Table 3. Transmission calculation

PATH: Perdrix Blanche to Lac Blue Sea

Effective height station 1	152 m	
Effective height station 2	50 m	
Distance in kilometers	55 km	
Transmitter power 1 watt		0 dBW
Cable and connector loss		-.5 dB
Antenna gain		10.0 dB
Effective radiated power		9.5 dBW
Free space loss	-117.0 dB	
Plane earth loss	dB	
Obstruction loss	dB	
Total propagation loss		-117.0 dBw
Received signal strength		-107.5 dBW
Antenna gain		10.0 dB
Cable and connector loss		-1.5 dB
Receiver input signal		-99.0 dBw
Minimum required signal		-137.0 dBw
Fade margin		38.0 dB

Table 4. Transmission calculation

PATH: Lac Blue Sea to Maniwaki

Effective height station 1	200 m	
Effective height station 2	10 m	
Distance in kilometers	10 km	
Transmitter power 1 watt		0 dBW
Cable and connector loss		-1.0 dB
Antenna gain		10.0 dB
Effective radiated power		9.0 dBW
Free space loss	-101.0 dB	
Plane earth loss	dB	
Obstruction loss	dB	
Total propagation loss		-101.0 dBw
Received signal strength		-92.0 dBW
Antenna gain		10.0 dB
Cable and connector loss		-0.75 dB
Receiver input signal		-82.75 dBw
Minimum required signal		-137.0 dBw
Fade margin		53.75 dB

The required test and tuning equipment is typical of that found at most forest protection radio shops. This would include a signal generator, deviation monitor, 12 volt power supply, watt meter, oscilloscope and voltmeter. The digital circuits require little tuning, as the only adjustment is a deviation potentiometer on the modulator board. The radios were tuned by following procedures outlined by the manufacturer. Some difficulty was encountered with the tuning and operation of the M7 and M8 transmitter power modules. In a few instances the modules exhibited a tendency to decrease in power over a period of time. Simple contact with an adjustment potentiometer would restore power. These modules were assumed to be defective and were replaced.

The transmitter was located in the same building as the lightning direction finder system at Le Domaine. The direction finder was equipped with a Y splitter cable of RS232 standard. Thus the data would be output to the telephone line and radio link simultaneously. Due to the limitation of the telephone line modem data was transmitted at 300 baud.

As the Le Domaine to Perdrix Blanche signal path was marginal, all equipment at the repeater site was installed in or near the fire tower cupola in an effort to minimize cable signal loss. The batteries and repeater were located in the fire tower cupola. The solar panel manufacturer recommends that the solar panels be within 8 meters of the batteries. The solar panels were mounted on the tower structure at the base of the cupola. The receiving and transmitting antennae were mounted above the cupola and were separated by a distance of 8 meters. At the Lac Blue Sea repeater site all equipment was located in a fire cache hut at the base of a 50 foot tower. The solar panel was mounted on a small frame near the ground and adjacent to the hut. The antennae were separated by a distance of 8 meters.

Data from the lightning direction finder had to be transmitted to the position analyzer located in the operations center at Maniwaki. The receiving antenna was mounted on the roof of the operations center and the radio receiver was mounted on an office wall. One pair of wires, 15 meters in length, transmitted the RS232 data signal from the receiver to the position analyzer. Experiments indicated that if high quality cable is used, the radio receiver and the position analyzer could be separated by a distance of at least 100 meters. The position analyzer is capable of accepting data from four direction finders. The SCO operates a network of three direction finders; thus one port (slot) was available for the radio link. As the radio link does not generate a DTR (Data Terminal Ready) signal, a jumper was installed in the radio cable connector to raise DTR. Thus the position analyzer was linked to the direction finder at Le Domaine by two separate but parallel data channels - one by conventional land line and one by the UHF radio system.

The position analyzer has several software features which allow for visual data checking and data comparison. These include a printed copy of raw data in record format and a copy of incoming data in byte streams (individual numbers) with error flags. Included in the error flags are framing, parity, and lost data errors. Framing bits indicate the start and end of data and the parity check allows for determining whether the bit pattern has changed while being transmitted. The position analyzer also provides automatic error monitoring. For a given time period, a count of data communication errors is

reported by the direction finder status message. These errors include illegal characters, illegal number of characters, framing or data overrun, and longitudinal parity. In addition the position analyzer was directly linked to the SCO main minicomputer (PDP 11/44). This link permitted the permanent disk storage of all data received from Le Domaine and provided the capability of monitoring radio link performance for one full fire season.

RESULTS

The system was installed in September, 1984. Table 5 is an example of hard-copy printout of the incoming data for the parallel data channels from Le Domaine. The preceding digit is the direction finder identification number. The number 3 indicates the telephone line from Le Domaine and the number 4 is the radio link from Le Domaine. The following two digits are numbers/characters generated by the direction finder. The results in column A indicate that the radio link is operating satisfactorily. The characters received on the radio link are identical to those received on the telephone link. Column B is an example of errors generated by the radio link. The results in column B were the result of unsuccessful attempts to implement the radio link. They are due to poor signal path, lack of transmitter power, noise, and poorly tuned radios. Errors include illegimate numbers, data dropout, and data overrun. The 20s in column B are framing error indicators.

Table 5. Incoming data from parallel radio and telephone link

	Column A (reliable data)	Column B (unreliable data)
radio link	4 96	4 96
telephone line	3 96	3 96
	4 5F	4 6F
	3 5F	3 6F
	4 00	4 E0
	3 00	3 00
	4 00	3 00
	3 00	4 23 20
	4 19	3 1A
	3 19	3 08
	4 08	4 EF 20
	3 08	3 14
	4 27	4 E6
	3 27	3 00
	4 00	
	3 00	

Monitoring incoming data provided for real time evaluation of system performance. For example, if it was suspected that other radio transmissions were causing data errors on the telemetry system, the incoming data would be monitored for errors at the time of transmission. Because of the large amount of hardcopy generated, monitoring of real time data was only used as a spot check on radio link performance.

Tables 6 to 9 describe the telemetry system performance over 8 hours. Results are embedded in the direction finder status message given by the position analyzer. Of interest are columns labelled ERRORS. These columns contain the total number of communication error events detected by the position analyzer for individual direction finder ports. The incoming data is checked for illegal characters, illegal number of characters, framing or data overrun errors, and longitudinal parity. Error monitoring is automatically initialized at midnight, and error counts are from midnight until the time a status message is requested.

In addition to sending lightning flash information, the direction finders send status information every 10 seconds. Column A of Table 5 is the character representation of such a message. Thus in an 8 h time period, if no lightning is sensed, approximately 400,000 bits of status information is transmitted by the direction finder. The SEEN column contains the number of lightning flashes reported to a communication port. Each flash is composed of 176 binary bits. Direction finders 1, 2, and 3 (DF column) are linked to the position analyzer by telephone line and DF 4 is the radio link.

For September 6th, 7th, and 10th most links exhibit good reliability with either one or no errors. The bit error rate can be expressed as 0 or 1 in 400,000. An error rate of 1 in 1,000,000 is often used as the reference for acceptable transmission line performance. The one exception occurred on September 7th where the position analyzer sensed 521 errors on the telephone line between Ft. Coulonge and Maniwaki. On September 11th some degradation of radio link performance was noted, when 24 errors and a loss of two lightning flashes was sensed by the position analyzer.

DISCUSSION

The first three of four objectives were achieved. A telemetry system was designed, licensed, and installed.

The specific design of the system depended on the application, existing constraints such as frequency availability and signal path, and applied constraints such as budget and minimum performance levels. If applicable, various alternatives should be considered. Lower radio cost and less signal path restriction may be achieved by using VHF. It should be noted that it may be more difficult to obtain VHF frequencies. Radios other than Repco can be utilized. Data links can be comprised of a mix of radio and land line. Sophisticated equipment and techniques are available to optimize radio frequency use. These facilities include error checking, frequency sharing, advanced modulation techniques, and polling. In general, increased sophistication may be achieved at some increase in cost.

Table 6. Error summary table

SEPTEMBER 6, 1984

**********DF STATUS**********

NAME	DF	LAST TIME	MILLISEC	VOLTAGE	SEEN	LOST	ERRORS
POS ANLYZR	0	08:43:04.609					
MANIWAKI	1	08:43:03.649	512	1027	1	0	1
COULONGE	2	08:42:46.341	364	1020	7	0	0
DOMAINE	3	08:42:47.738	356	1025	58	0	1
RADIO LINK	4	08:42:47.726	356	1025	58	0	1

Table 7. Error summary table

SEPTEMBER 7, 1984

**********DF STATUS**********

NAME	DF	LAST TIME	MILLISEC	VOLTAGE	SEEN	LOST	ERRORS
POS ANLYZR	0	08:00:44.053					
MANIWAKI	1	08:00:40.206	512	1026	0	0	0
COULONGE	2	08:00:44.662	364	1021	2	0	521
DOMAINE	3	08:00:39.715	356	1041	38	0	1
RADIO LINK	4	08:00:39.703	356	1041	38	0	1

Table 8. Error summary table

SEPTEMBER 10, 1984

**********DF STATUS**********

NAME	DF	LAST TIME	MILLISEC	VOLTAGE	SEEN	LOST	ERRORS
POS ANLYZR	0	07:54:20.707					
DOMAINE	3	07:54:07.149	356	1049	51	0	0
RADIO LINK	4	07:54:07.137	356	1049	51	0	0

Table 9. Error summary table

SEPTEMBER 11, 1984

**********DF STATUS**********

NAME	DF	LAST TIME	MILLISEC	VOLTAGE	SEEN	LOST	ERRORS
POS ANLYZR	0	08:10:48.441					
MANIWAKI	1	08:10:45.361	512	1027	0	0	0
COULONGE	2	08:10:25.273	364	1020	9	0	0
DOMAINE	3	08:10:49.710	356	1033	37	0	0
RADIO LINK	4	08:10:49.698	356	1033	35	0	24

Authorization for system implementation is a time consuming but relatively straightforward process. Numerous guidelines exist that describe DOC regulations and standards. If radios are certified for voice communication it may not be necessary to seek type approval for data transmission. The modulating technique is the determining factor. The tests on the DOE-406 radio were conducted in a private laboratory at a cost of $800. The DOC provides the service at a similar cost. Prior to any major expenditures or commitments an informal opinion by the DOC on the proposed configuration should be sought.

Implementation of the system required substantial assistance from the fire management organization. Available helicopter time was used for repeater installation. SCO voice radio expertise and test equipment were vital components of the implementation process. If these resources were specially contracted, most, if not all of the economic benefit would be lost. Justification of the system would be limited to a lack of communication alternatives. However the SCO supports a sophisticated voice radio network and the support of the data radio link was viewed as an extension of this service.

The final goal, of system evaluation and assessment of the potential for operational use, was partially realized. The system was dismantled in mid-September due to termination of the helicopter contract. The initial results, which are for a period of approximately two weeks, indicate that the radio link generally performs as well as the telephone lines and in one instance better than the telephone line. In addition, the results are for days when lightning activity occurred. Of some concern is the error rate on September 11th. The system will be reinstalled for the next fire season. We will be interested in error rates over long periods of time. If significant errors occur regularly, more than 1 in 1 million bits, attempts will be made to isolate the source of error. We are concerned about the fade margin, and interference from existing voice radio networks, lightning, atmospheric conditions, and X-band radar. However, as the system performed well for a two week period it is assumed that interference by other equipment will be minimal.

The radio system is designed to operate unattended for a complete fire season. The minimum maintenance required is installation in the spring and removal in the fall. A stock of selected spare radio modules should be maintained. Troubleshooting usually consists of identifying a faulty radio by a missing data tone and replacing a bad module. In general, maintenance of the system is similar to voice radio in that cables, connectors, antennae, power supply systems, and radio equipment must be maintained.

Preliminary results of the performance of the telemetry system outlined in this paper indicate that, for a limited time period, data can be economically and reliably transmitted on a continuous basis via an UHF radio link. If the system exhibits long term reliability it may be a feasible solution to problems associated with capturing data from remote areas. The economics of particular applications, support capability, and frequency availability are the major factors that determine the feasibility of installing similar systems.

ACKNOWLEDGMENTS

We want to express our appreciation to M. Prudhomme and A. Geggie of the Societe de Conservation de L'Outaouais, Maniwaki, Quebec, for their assistance in the installation and monitoring of the telemetry system. Dr. F. Kollar of the federal Department of Energy, Mines, and Resources provided thoughtful comments and suggestions, and J. Bussiere of the Ministere de l'Energie et des Resources du Quebec, Quebec, assisted in the preparation of the engineering brief.

REFERENCES

American Radio Relay League. 1982. The Radio Amateur's Handbook. Newington, Conn.

Bullington, K. 1957. Radio Propagation Fundamentals. The Bell System Technical Journal. 36: 593-626.

Chinnick, J.H. 1982. Engineering Report on Tests Conducted on Modified Repco Radios. Foundation Electronic Instruments Inc., Ottawa, Ont., FI Reference 82-800-80.

General Electric Company. 1962. VHF and UHF Propagation. Datafile Bulletin 1003-1. Datafile, Lynchburg, Va.

Meldrum, R.D. 1980. Engineering Brief: 450 MHz Telemetry System for Lower Mainland Seismic Array. Department of Geophysics and Astronomy, University of British Columbia.

Meteor Communications Consultants, Inc. 1981. An Introduction to Meteor Burst Communications. Kent, Wash.

Mroske, B.E.; Bussiere, J. 1983. Engineering Brief: UHF Telemetry System for Lightning Data Transmission. Can. For. Serv., Petawawa Natl. For. Inst.

APPENDIX I

Digital radio and modulation/demodulation

A digital mode of operation or digital radio can have several definitions. For purposes of this paper digital radio is the instantaneous modification of the operating radio frequency by a modulating circuit. A brief discussion of modulation and demodulation follows.

Computer data, in its most basic form, is represented by a series of ones and zeros or a series of on and off pulses. The ones and zeros are binary digits or bits. Data is stored and manipulated in this manner because most machines (devices) can retain one of two states reliably, such as positive or negative or high and low voltage. In the field of data communications the ones and zeros are often referred to as "marks" and "spaces." Electronic equipment often use two voltage levels to represent the mark and space.

Electronic circuits called modems modify the digital data (on and off pulses) into a waveform suitable for transmission over a radio frequency and restore the original digital form at a receiver site. The data is embedded (encoded) in the radio frequency by systematically altering some characteristic of the radio frequency waveform. The frequency or the phase is often shifted to achieve an on and off representation. This process is referred to as the modulation technique. If the frequency is shifted the radio frequency will assume a certain value for a one and another value for a zero. Modifying the frequency in this manner is referred to as Frequency Shift Keying modulation (FSK). If the radio frequency is shifted directly by the modulating circuit as compared to being shifted by a baseband frequency, the modulation technique is referred to as direct FSK. Demodulation consists of decoding radio frequency and restoration of the original one/zero pattern. The telemetry system described in this paper uses direct FSK modulation.

APPENDIX II

Radio transmission concepts

The distance over which a radio system can transmit data is dependent on transmission power, receiver sensitivity, operating radio frequency, and loss of transmission power between transmitter and receiver. A common unit for stating power loss and gain and receiver sensitivity is the decibel (dB). The decibel is a logarithmic ratio of power output to power input multiplied by ten. Thus, if the output is twice the power of the input the gain is 3 dB. The multiplication factor is twenty for voltage and current ratios. Power losses are prefixed by a minus sign. Thus a voltage ratio of 1 to 10 is -20 dB. Transmitter power in watts and receiver sensitivity in microvolts are converted to the decibel. Notations such as dBW and dBV are decibel values with respect to watt and volt ratios.

The available signal power at a receiver is calculated by subtracting power losses of the signal path from power available in the system. The resulting number is the "fade margin," which is defined as the amount of reserve power in dB available at a receiver to overcome effects of sudden atmospheric fades. The larger the fade margin the lower the data error rate. Fade margins between 20 to 30 dB are typical of acceptable minimums.

The available power in a system is dependent on receiver sensitivity, transmitter power, and antenna gain. These specifications are provided by the manufacturer. The loss of power between transmitter and receiver (signal path losses) are the result of several environmental influences such as atmosphere and terrain, and connecting equipment such as cables and cable connectors. Formulae and tables are available which provide reasonable approximations of signal path loss. Bullington (1957) and General Electric (1962) provide discussions of radio wave propagation. The Radio Amateur's Handbook provides cable and connector loss information.